2/11

An Fe-Ni-Cr-Co Alloy for Hot-Dip Galvanizing Hardware

C. M. Antony, S. K. Srivastava

Haynes International, Inc.
Kokomo, IN

Molten zinc is one of industry's most aggressive high-temperature environments. Current materials immersed in molten zinc do not hold up well and lead to excessive maintenance and down-time. Laboratory and field tests of several Fe-, Ni-, and Co-base alloys were conducted in hot-dip galvanizing zinc at 455°C (850°F). Based on these and other test results, it is shown that HAYNES® alloy 556 possesses the best combination of resistance to molten zinc, strength, fabricability, and weldability. The paper presents a life-cycle cost model for determining the cost effectiveness of using 556™ alloy.

H-3112
(2969d)

INTRODUCTION

The galvanizing kettle and auxiliary equipment are critical parts of the galvanizing process(1). Proper material selection for galvanizing equipment is essential for cost effective operation. Failure to properly select the most suitable material for equipment accessories can lead to high maintenance life-cycle costs due to extensive repair and replacement, catastrophic failure of equipment and subsequent loss of expensive workpieces, and decreased throughput due to downtime and poor thermal mass considerations for equipment in the original design.

Two overriding factors are key to material selection for galvanizing equipment. The alloy must possess adequate mechanical strength at temperature and resistance to corrosion from molten zinc. Often mechanical failures occur as a result of corrosion. The alloy corrodes over time and the component loses its load carrying capability. Failure typically results due to tensile overload, thermal fatigue (especially in welds), or stress rupture. Additionally, the alloy must be resistant to embrittlement and associated cracking, and be metallurgically stable so that it can be repaired by either welding or mechanical working.

Many materials will work in galvanizing operations, but the length of continuous service varies drastically. Typical materials of construction include carbon steel, boiler plate steel, and stainless steel. (Table I lists the nominal composition of alloys cited throughout this paper). Carbon steels tend to fail quickest while stainless steels increase life, but are not considered satisfactory. In the past several years, Haynes International, Inc. received inquiries from numerous hot-dip galvanizing mills indicating unsatisfactory performance or problems with existing materials. In a few instances, equipment such as thermowells, probes, etc. have been fabricated from 556 alloy and these are performing satisfactorily. It is believed that a material which will combine increased resistance to molten zinc concomitant with strength will fulfil an important industrial need.

The purpose of this paper is to review the relevant characteristics of 556™ alloy, report on field trials in hot-dip galvanizing zinc which directly compare various alloys typically used in construction of equipment, and present a simple economic model for determining of the cost-effectiveness of switching to 556 alloy.

556 ALLOY

HAYNES alloy 556 is an iron-nickel-chromium-cobalt alloy which possesses outstanding high temperature strength and corrosion resistance. Because of its composition, 556 alloy possesses good resistance to a variety of corrosive atmospheres including those which are sulfidizing, oxidizing, carburizing, and chlorine bearing in nature. It is difficult to say without question the contribution of the individual elements on the alloy's properties, but some generalities can be stated. The nickel is known to stabilize the alloy's austenitic crystallographic structure, chromium and lanthanum improve oxidation resistance, the refractory elements improve strength, and cobalt contributes to resisting sulfidation attack.

The alloy is solid solution strengthened and does not require heat treatment to increase strength. It is solution heat treated at 1177°C (2150°F) and rapidly cooled for optimum properties. Figure 1 shows a comparison of the ultimate tensile strength, 0.2% offset yield strength, and elongation at room temperature and 455°C (850°F) for 556 alloy and other commonly used galvanizing equipment alloys. As seen in the plot, 556 alloy is 30-40% stronger (yield strength) at 455°C (850°F) than 304 SS, 316 SS, and 800H alloy, an iron-based alloy. The increase strength offers the potential for reduction in cross-section thickness while maintaining a strength improvement over conventional alloys.

Galvanizing equipment is periodically cycled through an acid dip for cleansing of adherent zinc. Also, equipment such as baskets, fixtures, hooks, etc. are continuously cycled through an acid bath, flux (zinc ammonium chloride) and hot-dip galvanizing zinc. Therefore, resistance to the corrosive nature of acid is another factor which must be considered. Table II shows the corrosion rate of 556 and 316 SS alloys in various concentrations of sulfuric acid for 4-24 hour periods. Table III shows the corrosion rates in various concentrations of hydrochloric acid. As seen, 556 alloy shows substantial improvement over 316 SS. The exception would be in boiling hydrochloric acid (1% concentration) where both alloys behave similarly. It is believed that the improvement is the same over other 300 series stainless steels.

The 556 alloy possesses excellent weldability and is easily fabricated. Figure 2 shows all-weld-metal tensile properties for GTAW weldments. As seen, the yield strength of all-weld-metal specimens is higher than wrought properties. Additionally, the alloy maintains good ductility, which is essential for components being thermally cycled and failing due to thermal fatigue.

LABORATORY AND FIELD EVALUATIONS

Table IV shows metal loss results of a laboratory corrosion test in which alloys were exposed to pure molten zinc for 50 hours at 455°C (850°F). Figure 3 shows corresponding cross-section thickness profiles of selected alloys. No internal penetration was noted in any of the alloys. The results show that the Fe-based 556 alloy suffered the least amount of metal loss. The Co-based alloy 25 and alloy 188 ranked next ahead of the stainless steels and 800H. High nickel alloys performed most poorly in the laboratory molten zinc exposures.

Field evaluations are probably the most appropriate method to determine an alloy's suitability to a particular environment. Generally, the corrosive media, as well as the service conditions, are so complex, they are nearly impossible to duplicate in a laboratory.

A multiple coupon test rack trial, consisting of 556, 188, 25 and 316 SS alloys, was conducted at a large steel manufacturer. The objective of the field test was to determine a suitable alloy for a sink roll rig. Carbon steel was used as a support structure and was replaced every 4-6 months due to loss of 50% of original thickness. Stainless steel (316 SS) was used for the rolls. Reportedly, the rolls lost 1/16 inch of metal every two weeks.

Two test racks were exposed to the following cycle: molten zinc (0.10-0.12% Al) for 152 hours in one rack and approximately 2500 hours of service for the other rack. The location of the test rack in the sink roll rig is shown in Figure 4. Table V lists results of metal loss for both time exposures. The 316 SS sample in the 2500 hour exposure was perforated. The as-received condition of the test coupons, which accumulated 2500 hours, is shown in Figure 5.

Although alloy 25 suffered the least amount of metal loss for both exposures, it exhibited extensive cracking after the 152 hour exposure. Similarly, 316 SS exhibited severe cracking during the same exposure. Figure 6 shows the multiple cracks formed in alloy 25 and cracking of 316 SS. It is believed that the cracks are related to liquid metal embrittlement. The 556 alloy is therefore considered most suitable due to its good resistance to metal loss and resistance to cracking.

At another hot-dip galvanizing mill, sink rolls made of 316 SS were replaced every week. The repairable rolls were resurfaced and reused until a time at which the rolls failed by cracking at the roll neck. They were then scrapped. A field test was carried out to identify a material less susceptible to cracking and more cost effective. A test rack consisting of 316 SS, 556, 309 SS, carbon steel and RA 330® alloys was exposed to the molten zinc operating at 455°C (850°F) for four weeks. Table VI shows results of metal loss per side for each of the alloys.

The 316 SS suffered the least amount of metal loss in this trial followed by 556, 309 SS, carbon steel, and RA330, respectively. No cracking was detected in the 316 SS coupon in this trial. However, in contrast to a fabricated component, it is not uncommon for an unrestrained coupon not to suffer any cracking. Besides, the sink rolls made of 316 SS in this application experienced cracking resulting in scrapped rolls. The 316 SS exhibited best resistance to molten zinc but has propensity for cracking while in service. For these reasons, it is believed 556 alloy is the best choice.

LIFE-CYCLE COST ANALYSES

The purpose of this section is to develop a simple model for material users to help determine the economic benefits of using 556 alloy for galvanizing applications. The sample analyses presented are hypothetical, but based on realistic costs and financial figures used by galvanizers.

When determining whether to consider a material upgrade, it is recommended that the operation time required for a break-even investment be determined. A simple approach would be to estimate the break-even life required based on the added cost of a material upgrade and compare that with the estimated component life extension based on laboratory corrosion data or actual field trial data. This approach assumes the component fails due to corrosion.

Life cost of original equipment includes the material and labor costs of original construction plus the material and labor costs of overhaul repair. Substitute the material cost of the upgraded material and modify the fabrication and repair costs accordingly to come up with upgraded equipment costs. If the design is changed such that less material is used or less welding is required, this must also be taken into account. Additionally, repair costs may go down, or go away, over the course of the original equipment life. Divide the upgraded equipment costs by the original equipment costs and one will obtain a break-even life factor to a first-degree approximation which must be met for consideration of a new material.

Next, life extension of the equipment based on material laboratory corrosion data or field trial data is estimated. This number should be compared with the break-even factor based on material costs. The comparison should be evaluated carefully. When the comparison shows that life extension based on material corrosion data is far greater than the break-even life required, it is obvious that a trial component should be made or a material upgrade is in order.

Under some circumstances, the material upgrade may still be worth considering when the opposite occurs. This is because a number of important factors were not included in our model. These include:

- furnace throughput costs (reduced section thickness may improve throughput)
- labor cost reduction due to increased throughput
- kettle operation costs may be reduced (kettle rating may be improved)
- increased kettle production capacity - may effect other plant departments (increase overall plant efficiency)
- increased equipment reliability (avoiding potential loss of expensive workpieces).

These factors should be considered when conducting a more in-depth economical analysis of the potential use of a material upgrade.

Shown in Appendix A is a hypothetical economic analysis for the use of 556 alloy as a zinc pot basket instead of a carbon steel basket with MONEL® alloy and stainless steel accessories. As shown, the break-even life improvement required, as determined by upgraded basket costs which correspond to a 33% reduction in overall material needs, is 3.4 years. The laboratory corrosion data in pure molten zinc estimates an 8.8 year extension in life with 556 alloy compared to 304 SS. It is projected that carbon steel would perform worse than 304 SS. Therefore, it is deemed advisable to consider switching to 556 alloy as material of construction or conduct a component field trial evaluation.

Other costs such as increased capacity through the kettle, savings on labor costs in the galvanizing department and savings associated with overall plant efficiency improvement were not considered in this analysis. Savings in these areas would offset the new basket life-cycle costs and subsequently decrease the required break-even life to a number less than 3.4 years. These savings would also allow computation of the payback period (basket investment/net annual savings), which is helpful in determining whether the investment is worth considering further.

CONCLUSIONS

- The 556 alloy offered substantial strength improvements over commonly used galvanizing equipment alloys allowing for reductions in component thickness.
- The 556 alloy is overall more resistant to sulfuric and hydrochloric acid corrosion attack than 316 SS alloy.
- The 556 alloy is easily fabricated and exhibits excellent GTAW all-weld-metal tensile properties.
- Laboratory corrosion tests in pure molten zinc show 556™ alloy to be better than ferritic and austenitic stainless steels as well as other Fe-base alloys.

- Field tests in hot-dip galvanizing environments support laboratory corrosion testing.
- A basic model using life-cycle cost analysis shows that a 556 alloy material upgrade for hot-dip galvanizing hardware can be financially beneficial.

HAYNES and HASTELLOY are registered trademarks of Haynes International, Inc.

556 is a trademark of Haynes International, Inc.

RA330 is a registered trademark of Rolled Alloys, Inc.

MONEL is a registered trademark of INCO family of companies

REFERENCES

1. "Hot Dip Galvanized Coatings", ASM Metals Handbook, Vol. 5, Ninth Edition, 1982, ASM, Metals Park, OH.

2. S. K. Srivastava, Proc. Symposium on Performance of Materials in Fluidized Bed Combustion and Process Industries, ASM Materials Congress, 10-15 Oct. 1987, Cincinnati, OH.

TABLE I

Nominal Composition of Tested Alloys

					wt %			
Alloy	C	Fe	Ni	Co	Cr	Mo	W	Others
HAYNES® alloy 556	.10	Bal	20	18	22	2.5	2.5	.2N, 0.6 Ta, .02 Zr, .02 La
800H	.05	Bal	32.5	-	21	-	-	.4 Al, .4 Ti
RA330® alloy	.05	Bal	35	-	19	-	-	1.7 Si, .17 N
316 SS	.08	Bal	12	-	17	2.5	-	
309 SS	.10	Bal	13.5	-	23	-	-	
304 SS	.08	Bal	9.5	-	19	-	-	
446 SS	.02	Bal	-	-	25			.25 N*
C Steel	.20	Bal	-	-	-	-	-	.45 Mn, .25 Si
HAYNES alloy 188	.10	3*	22	Bal	22	-	14	.04 La
HAYNES alloy 25	.10	3*	10	Bal	20	-	15	
HASTELLOY® alloy X	.10	19	Bal	1.5	22	9	0.6	
HAYNES alloy 625	.10	5*	Bal		21	9	-	3.6 Cb

*maximum

HAYNES and HASTELLOY are registered trademarks of Haynes International, Inc.

RA330 is a registered trademark of Rolled Alloys, Inc.

TABLE II

Corrosion Resistance of 556™ alloy and 316 SS in Sulfuric Acid

4 - 24 Hour Periods

			Corrosion Rate (mpy) Temperature	
Concentration	Alloy	Room Temp.	66°C (150°F)	Boiling
20%	556	0.1	10.4	319
	316	2.0	202	11,103
10%	556	0.1	0.1	137
	316	1.4	17.8	768
2%	556	-	-	35.7
	316	-	-	147

556 is a trademark of Haynes International, Inc

TABLE III

Corrosion Resistance of 556™ alloy and 316 SS in Hydrochloric Acid

4 - 24 Hour Periods

Concentration	Alloy	Room Temp.	Corrosion Rate (mpy) Temperature 66°C (150°F)	Boiling
10%	556	15.7	1254	-
	316	63.6	3408	-
5%	556	15.7	968	6568
	316	-	1020	6008
2.5%	556	0.2	144	2290
	316	10.1	306	2069
1%	556	0.2	0.2	169
	316	3.5	22.8	920

TABLE IV

Corrosion of Alloys Exposed in 455°C (850°F) Zinc for 50 Hours

Alloy	Metal Loss, m (mils)*
556 alloy	40.6 (1.6)
25	58.4 (2.3)
188	63.5 (2.5)
446	236.2 (9.3)
800H	279.4 (11.0)
304	358.1 (14.1)
625	609.6 (24.0) **
X	609.6 (24.0) **

* No internal penetration noted with any of the alloys tested

** Sample dissolved

TABLE V

Results of Field Evaluation at Steel Manufacturer - 1

Exposure: 152 Hours

Alloy	Metal Loss, m (mils) *	Cracking
25	50.8 (2.0)	severe - 62 mils
556 alloy	83.8 (3.3)	none
188	83.8 (3.3)	none
316	147.3 (5.8)	severe - 80 mils

Exposure: 2,500 Hours

Alloy	Metal Loss, m (mils) *	Cracking
25	228.6 (9.0)	none
556 alloy	381.0 (15.0)	none
188	520.7 (20.5)	none
316	1104.9 (43.5) - perforated	none

*no internal penetration noted with any samples

TABLE VI

Results of field Evaluation at Steel Manufacturer - 2

Exposure: 672 Hours

Alloy	Metal Loss, m (mils) *
316	147.3 (5.8)
556 alloy	276.9 (10.9)
309	660.4 (26.0)
carbon steel	998.2 (39.3)
RA330 alloy	1574.8 (62.0) - perforated

* no internal penetration noted with any samples

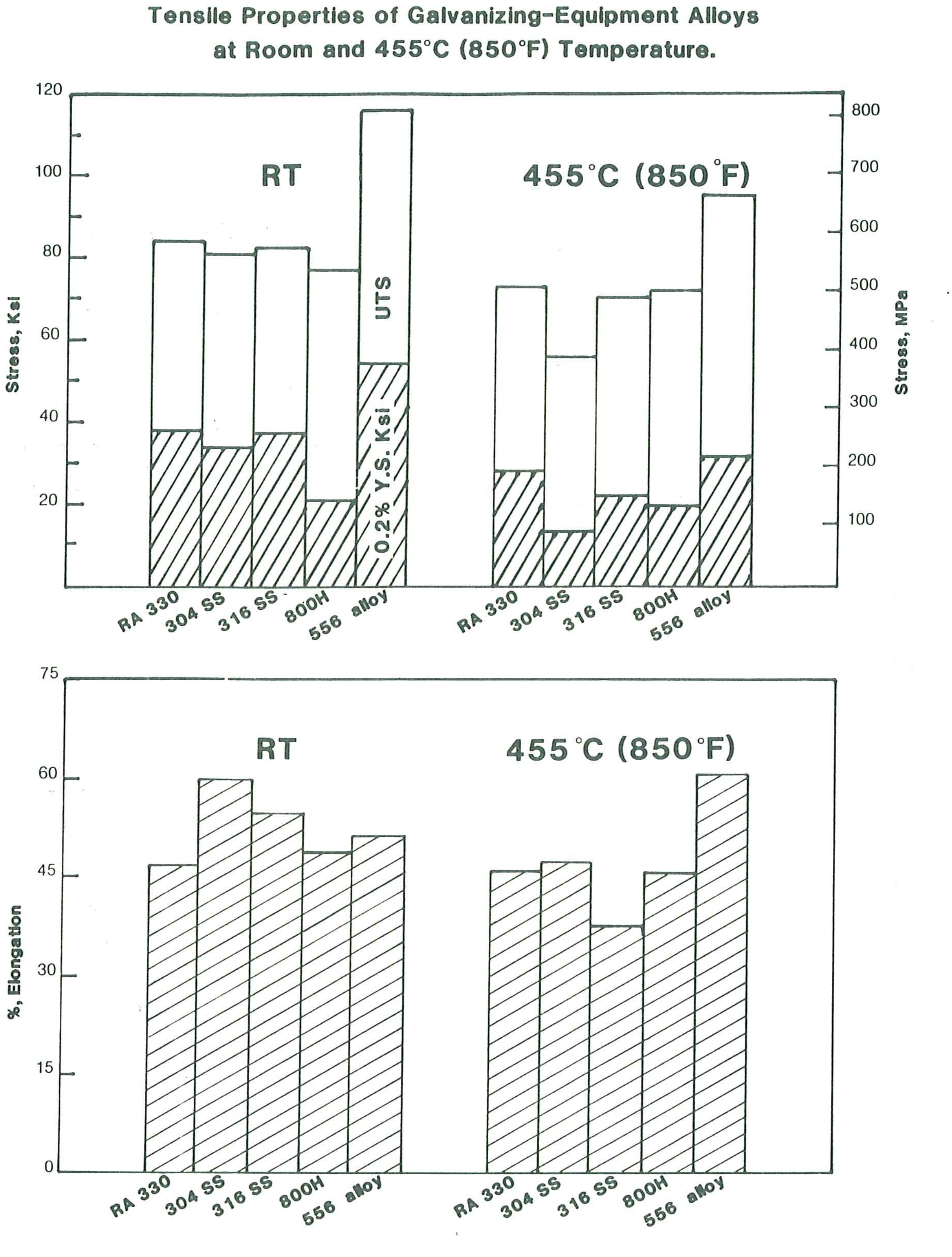

Figure 1. Tensile properties of galvanizing equipment alloys at room and 455°C (850°F) temperatures.

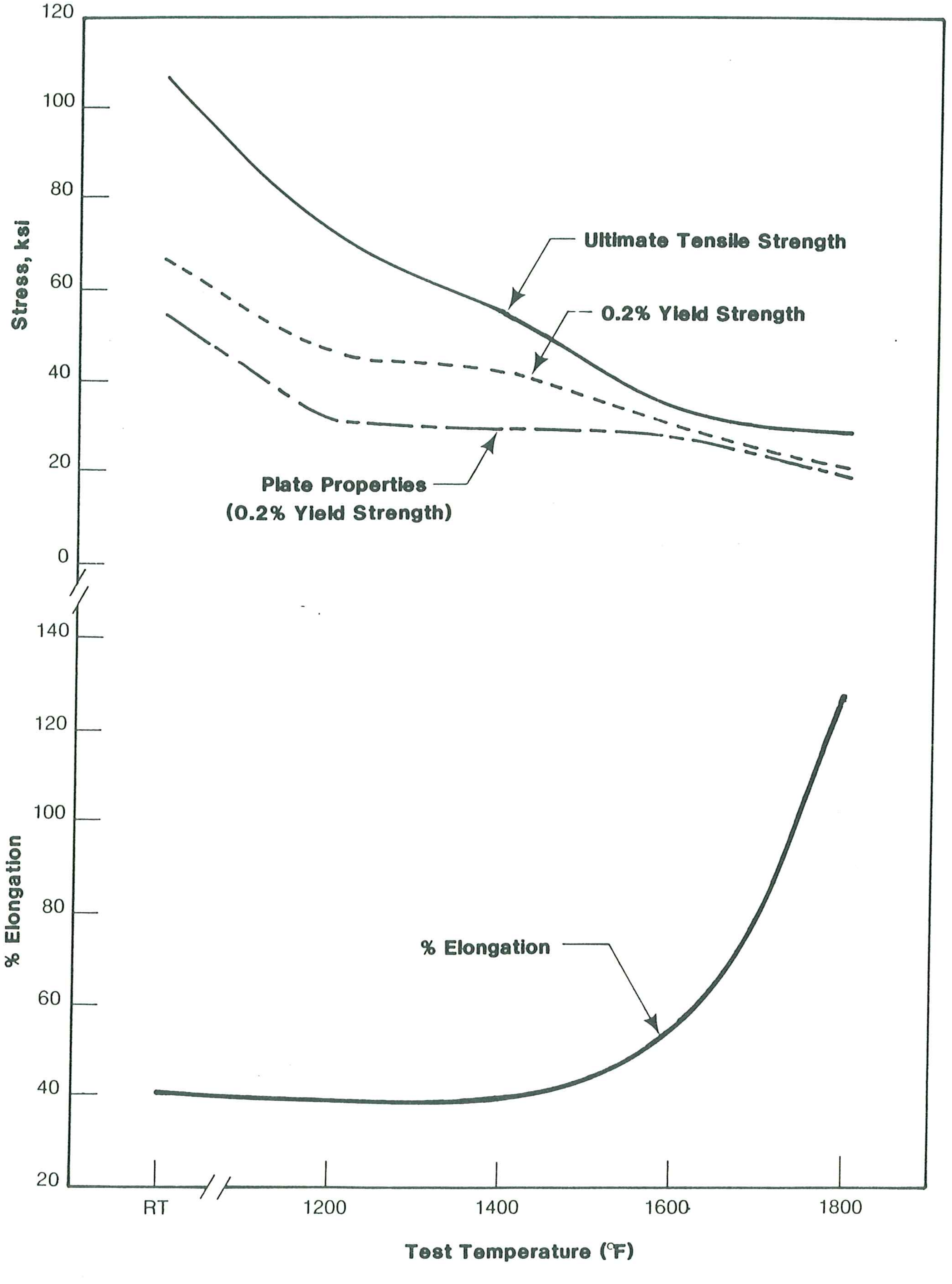

Figure 2. Typical all-weld-metal tensile properties for 556 alloy generated from GTAW cruciform weldment specimens.

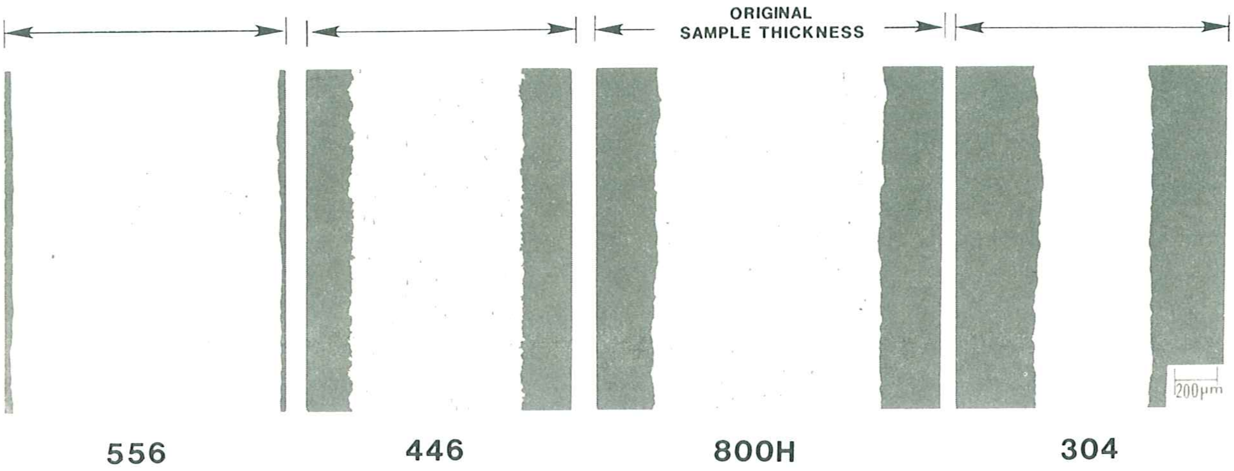

Figure 3. Cross-section profiles of selected alloys following 50-hour exposure in 455°C (850°F) molten zinc. (2)

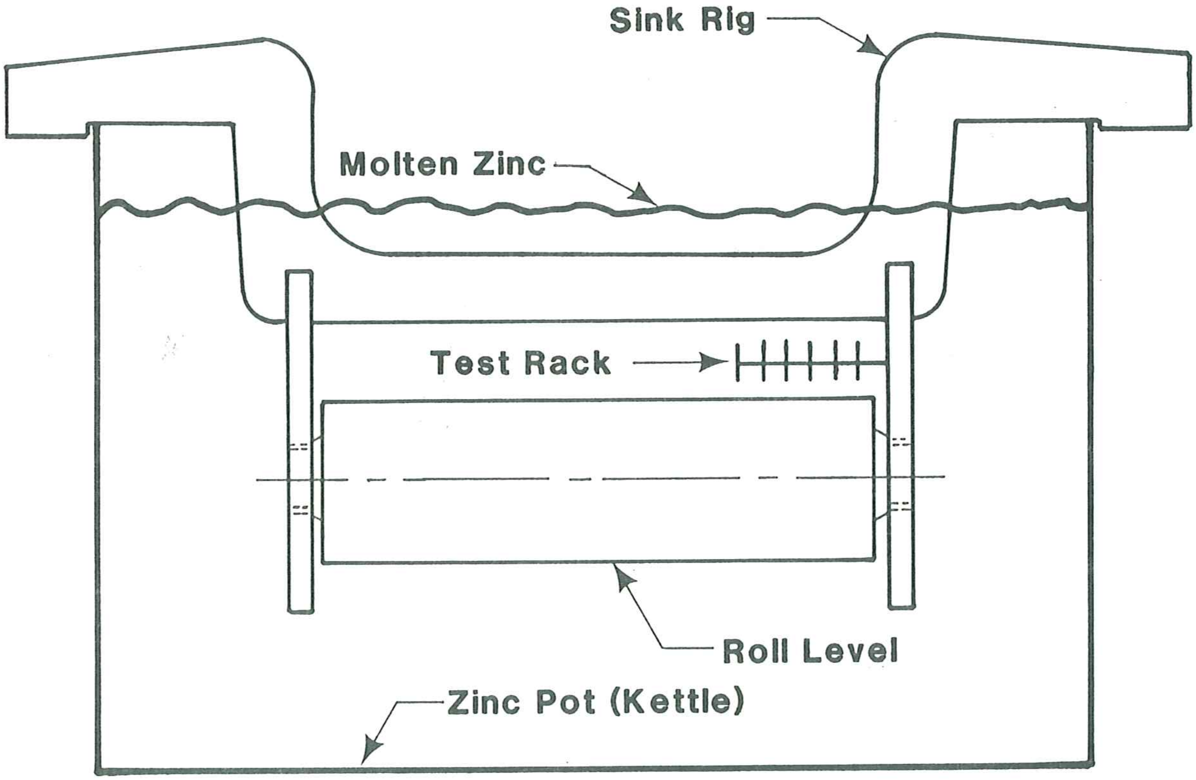

Figure 4. Location of test rack in sink roll rig.

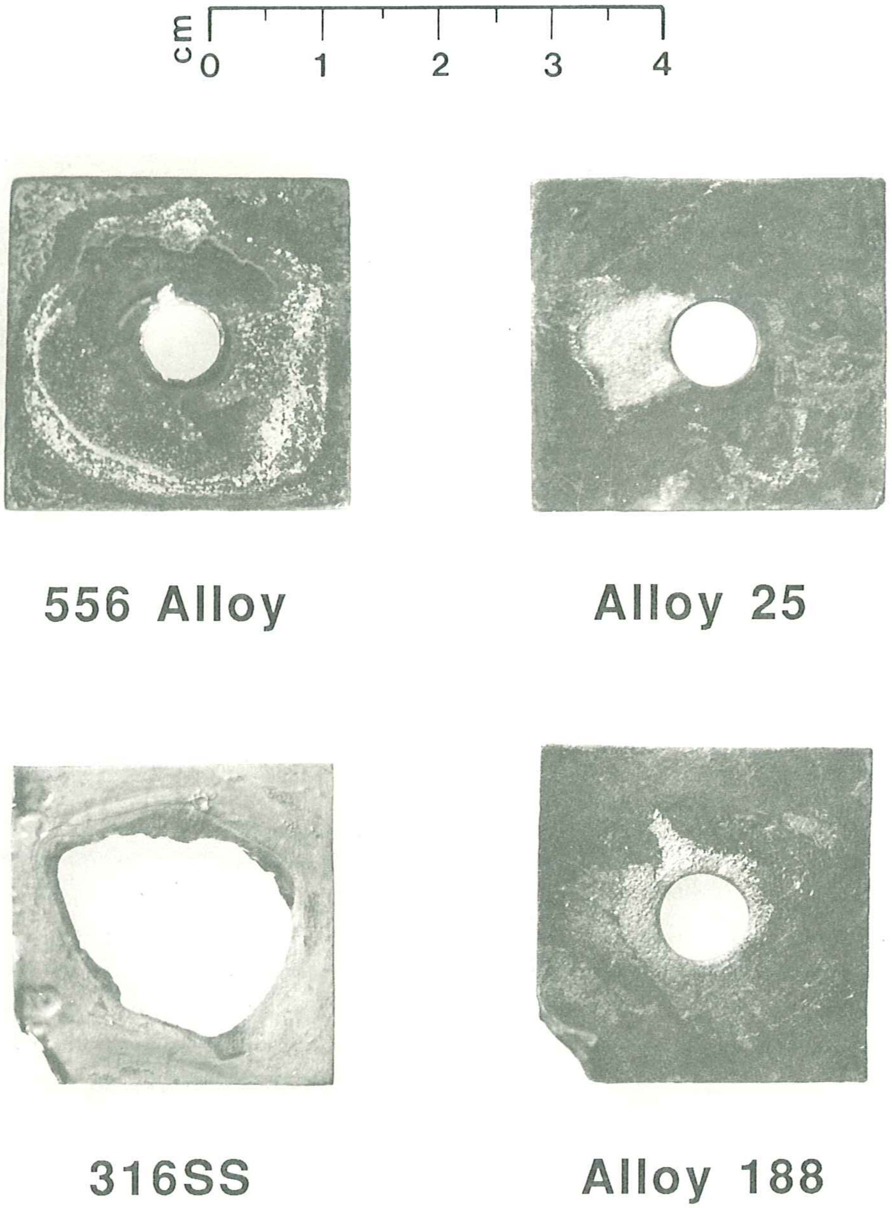

Figure 5. Appearance of the as-received coupons after 2500-hour exposure in the molten zinc at 455°C (850°F).

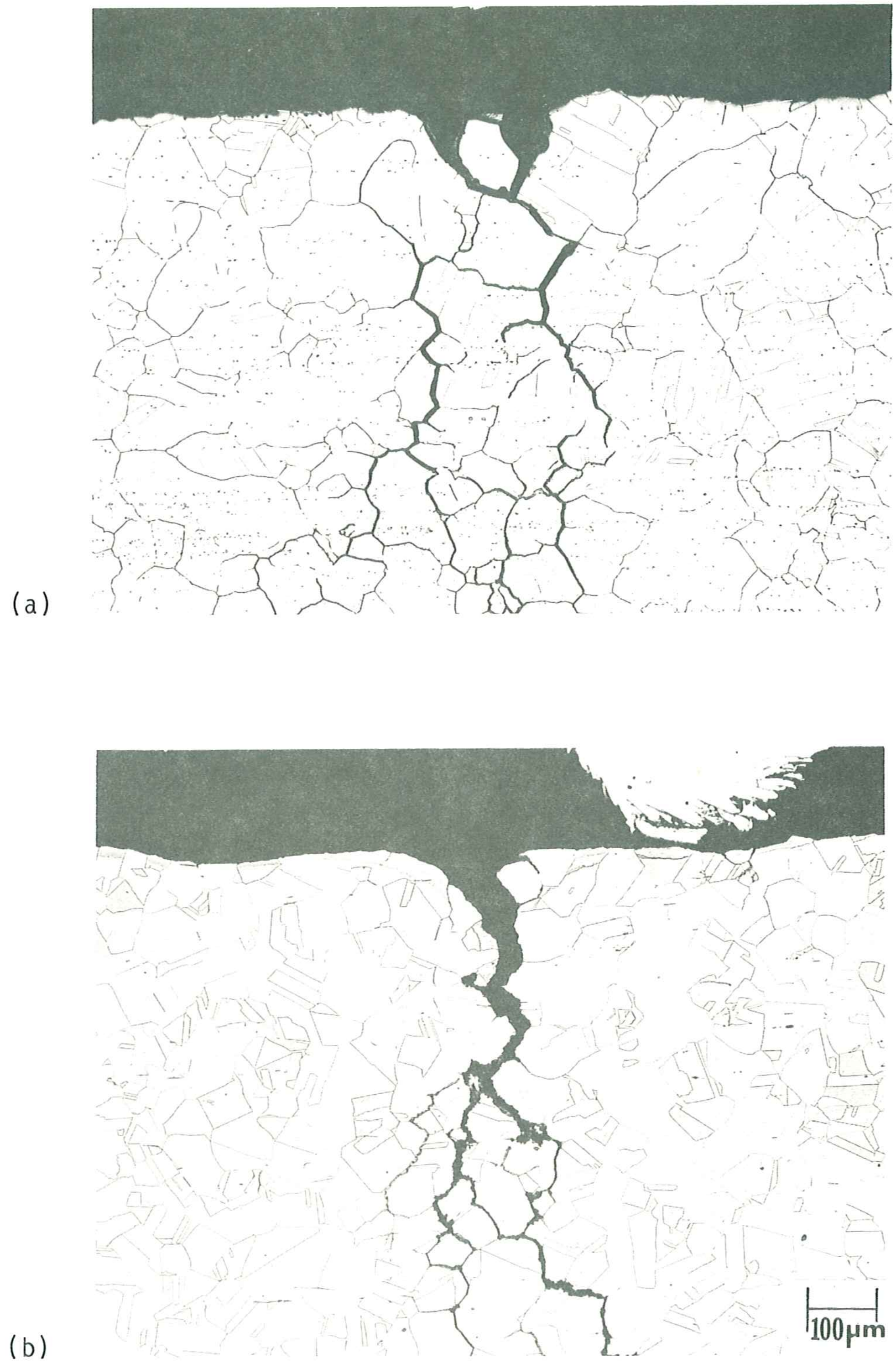

Figure 6. Cracks formed in test coupons following 152-hour exposure: a - alloy 25; b - 316 SS (2)

APPENDIX A

Example of Life-Cycle Cost Justification

Original construction:

Component weight = 85 lbs
Component life = 1 year
Component construction: carbon steel, MONEL® alloy, stainless steel

Assumptions:

- No savings associated with 556 alloy baskets used in simulation. (Savings such as increased capacity in the galvanizing department, overall plant efficiency, increased component reliability, etc. would be realized in actual application.)
- Current failure is due to corrosion

EQUIPMENT COSTS

Original component costs/per piece of equipment/year:

material costs:	$ 90.00
fabrication costs (@ $25.00/hour):	95.00
yearly maintenance costs:	50.00
original equipment costs	$235.00

556™ alloy component costs/(for first year):

material costs (based on 2/3 original thickness)	$700.00
fabrication costs (@ $25.00/hour):	100.00
yearly maintenance costs:	0.00
556 alloy equipment costs	$800.00

BREAK-EVEN LIFE

Break-even life factor = 556 alloy equipment costs/original equipment costs
= $800.00/235.00
= 3.4

Break-even life required = (life factor)(current life)
= (3.4)(1 year)
= 3.4 years

ESTIMATED LIFE IMPROVEMENT

Estimated life improvement based on laboratory corrosion data:

amount of attack to pure molten zinc at 455°C (850°F)

Alloy	Metal loss (mils)
556	1.6
304 SS	14.1

estimated life improvement = metal loss for 304 SS/metal loss for 556 alloy
= 14.1/1.6
= 8.8 years

CONCLUSION:

Conduct a field evaluation or switch to 556 alloy.

List of Figures

HAYNES
International

Haynes International, Inc.
1020 West Park Avenue, P.O. Box 9013
Kokomo, Indiana 46904-9013

Condensed Product List

ALLOYS

High-Performance Corrosion-Resistant Alloys
- HASTELLOY® alloy B-2
- HASTELLOY alloy C-4
- HASTELLOY alloy C-22
- HASTELLOY alloy C-276
- HASTELLOY alloy G-3
- HASTELLOY alloy G-30
- HASTELLOY alloy G-50
- HASTELLOY alloy H-9M
- HASTELLOY alloy N
- ULTIMET™ alloy

Super Stainless Steel
- FERRALIUM® alloy 255

Titanium Alloy
- HAYNES® alloy Ti-3Al-2.5V

High-Performance Heat-Resistant Alloys
- HASTELLOY alloy X
- HASTELLOY alloy S
- HASTELLOY alloy W
- HAYNES alloy 25
- HAYNES alloy 31
- HAYNES alloy R-41
- HAYNES alloy HR-160
- HAYNES alloy 188
- HAYNES alloy 214
- HAYNES alloy 230
- HAYNES alloy 242
- HAYNES alloy 263
- HAYNES alloy 556
- HAYNES alloy 625
- HAYNES alloy 718
- HAYNES alloy X-750
- MULTIMET® alloy
- WASPALOY™ alloy

FORMS

- Sheet
- Plate
- Coils
- Strip
- Billet
- Wire
- Seamless Pipe and Tubing
- Welded Pipe and Tubing
- Bar
- Remelt Materials

PROPERTIES DATA

The data and information in this publication are based on work conducted principally by Haynes International, Inc. and are believed to be reliable. However, we do not make any warranty or assume any legal liability or responsibility for its accuracy, completeness or usefulness, nor do we represent that its use would not infringe upon private rights. Any suggestions as to uses and applications for specific alloys are opinions only and Haynes International, Inc. makes no warranty of results to be obtained in any particular situation.

101190

For More Information Contact:

Kokomo, Indiana 46904-9013
1020 W. Park Avenue
P.O. Box 9013
Tel. 800-342-9637-(High-Temp)
800-354-0806-(Corrosion)
Telex: 272280
FAX: 317-456-6905

Anaheim, California 92806
Stadium Plaza
1520 South Sinclair Street
Tel: 714-978-1775
800-531-0285
TWX: 910 591 1884
FAX: 714-978-1743

Arcadia, Louisiana 71001-9701
(Tubular Products Only)
Highway 80 West
Route 1 Box 8
Tel: 318-263-9571
Telex: 588427
FAX: 318-263-8088

Windsor, Connecticut 06095
430 Hayden Station Road
Tel: 203-688-7771
800-426-1963
FAX: 203-688-5550

Houston, Texas 77041
The Northwood Industrial Park
12241 FM 529
Tel: 713-937-7597
800-231-4548
Telex: 225465
FAX: 713-937-4596

Brazil
Avenida Paulista 2001
Conj 1704, 01311 Sao Paulo-SP
Tel: 289-0900 and 289-0622
Telex: 11 22510

England
Haynes International, Ltd.
P.O. Box 10
Parkhouse Street
Openshaw
Manchester, M11 2ER
Tel: (061) 223-5054
Telex: 667611
FAX: 061-223-2412

France
Haynes International, S.A.R.L.
43 Rue de Belluvue
Boite Postale No. 47
92101 Boulogne Cedex
Tel: (01) 48 25 22 76
Telex: 631417
FAX: (01) 48250251

Switzerland
Nickel Contor, AG
Gotthardstrasse 21
CH-8022 Zurich
Tel: (01) 201 73 22
Telex: 815-601
FAX: (01) 201 73 33

Printed in U.S.A.